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PRESSURE DISTRIBUTION MEASUREMENTS ON THE MARK 25 TORPEDO

THE HIGH SPEED WATER TUNNEL
CALIFORNIA INSTITUTE OF TECHNOLOGY.
PASADENA, CALIFORNIA

SECTION Nº 6.1-sr207-2248

LABORATORY Nº ND-30.5

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ON THE
MK 25 TORPEDO

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Section No. 6.1-sr207-2248

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ABSTRACT AND SUMMARY

This report covers measurements of the pressure distribution around the body of the Mk 25 Torpedo equipped with a shroud ring tail, and includes studies of the effect on the pressure distribution of variations in yaw and pitch angles, velocity, and static pressure (i.e., submergence). The tests were made on a 2-inch diameter model (model scale 1 to 11.21).

In addition to providing a general picture of the pressure distribution as affected by the different variables, the data presented herein are useful in determining the best locations and arrangements for the pressure intakes to the immersion mechanism and to the depth and roll recorder, and also as a check on cavitation measurements. Because the pressures on the fins themselves were not measured in these tests, the data cannot be used to calculate overall forces acting on the complete torpedo.

The main observations and conclusions are summarized in the following paragraphs:

1. Within the range of these tests, the pressure distribution, as presented in terms of p/q, was found to be independent of variations in velocity and static pressure or submergence. That is, the difference between the pressure at any station on the body and the static pressure of the undisturbed water is independent of the static pressure and is directly proportional to the velocity head.

2. The pressure on the surface of this torpedo equals the static pressure of the undisturbed water at two positions, one on the projectile nose and one on the afterbody (see Figure 4). Ahead and behind these two stations the pressure is above static, while between the two (which includes about 80 per cent of the overall length) the pressure is below static.

3. The position on the afterbody at which p/q = 0 is only slightly affected by yaw or pitch angles up to 6 degrees.

4. On the basis of these measurements, made without rotating propellers, it appears that the best arrangement for the pressure intake to the immersion mechanism would be through a piezometer ring connecting to four pressure taps on the 45-degree planes between the fins and about 28 inches ahead of the end of the tail. The pressure imposed on the diaphragm would then be equal to true hydrostatic pressure, and practically independent of yaw or pitch. The influence of the propellers may shift this point slightly either aft or forward.

5. Placing the pressure take-off for the depth and roll recorder where $p/q = 0$ on the nose is not recommended because the pressure in this zone changes rapidly with yaw. Connection of the depth and roll recorder to the point of the afterbody where $p/q = 0$ is, of course, physically impracticable. It is recommended, therefore, that the pressure intake be left unchanged and, if necessary, determinations be made of the corrections to be applied to the depth record.

PRESSURE DISTRIBUTION MEASUREMENTS ON THE MARK 25 TORPEDO

INTRODUCTION

This report is the sixth in a series on the new Mk 25 Torpedo. Four of the preceding reports[1], [2], [3], [4] dealt with the development of suitable arrangements of the exhaust passages and stacks designed to discharge the exhaust gases through hollow fins instead of the normal arrangement wherein the exhaust gases are discharged through hollow propeller shafts. The fifth report[5] in this series covered the measurement of forces and moments on the Mk 25 Torpedo with various exhaust outlet arrangements.

The tests reported herein were made to investigate the pressure distribution about the body of this torpedo, and to study the effect on the pressure distribution of variations in velocity, static pressure (submergence), and orientation with respect to the line of travel. The tests were made on a 2-inch diameter model in the High Speed Water Tunnel at the California Institute of Technology, and were authorized by Dr. E. H. Colpitts, Chief of Section 6.1, National Defense Research Committee, in a letter dated October 8, 1943.

The data presented herein, in addition to providing a general picture of the pressure distribution, are useful for determining the best location for the pressure intake to the depth control (immersion) diaphragm, and for determining whether the location of the depth and roll recorder is such as to enable the device to indicate actual running depth. The data may also be used to check the cavitation characteristics of the torpedo.

The tests made included measurements of the pressure distribution about the Mk 25 Torpedo fitted with a ring tail but without exhaust stacks, under conditions of constant velocity and constant static pressure, and with varying yaw between -6 and +6 degrees. Additional tests were made to determine the effect, if any, of variations in static pressure and velocity on the pressure distribution.

APPARATUS AND TEST PROCEDURES

DESCRIPTION OF THE TORPEDO

The Mk 25 is a newly developed aircraft torpedo of the same overall dimensions as the Mk 13-1. It was designed structurally to withstand drops from aircraft at higher speeds and altitudes

(1) Numbers in parentheses refer to references listed at end of this report.

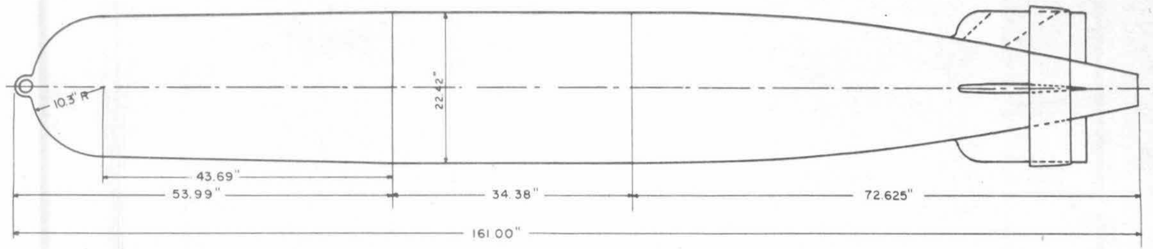


FIG. 1 - OUTLINE OF MK 25 TORPEDO

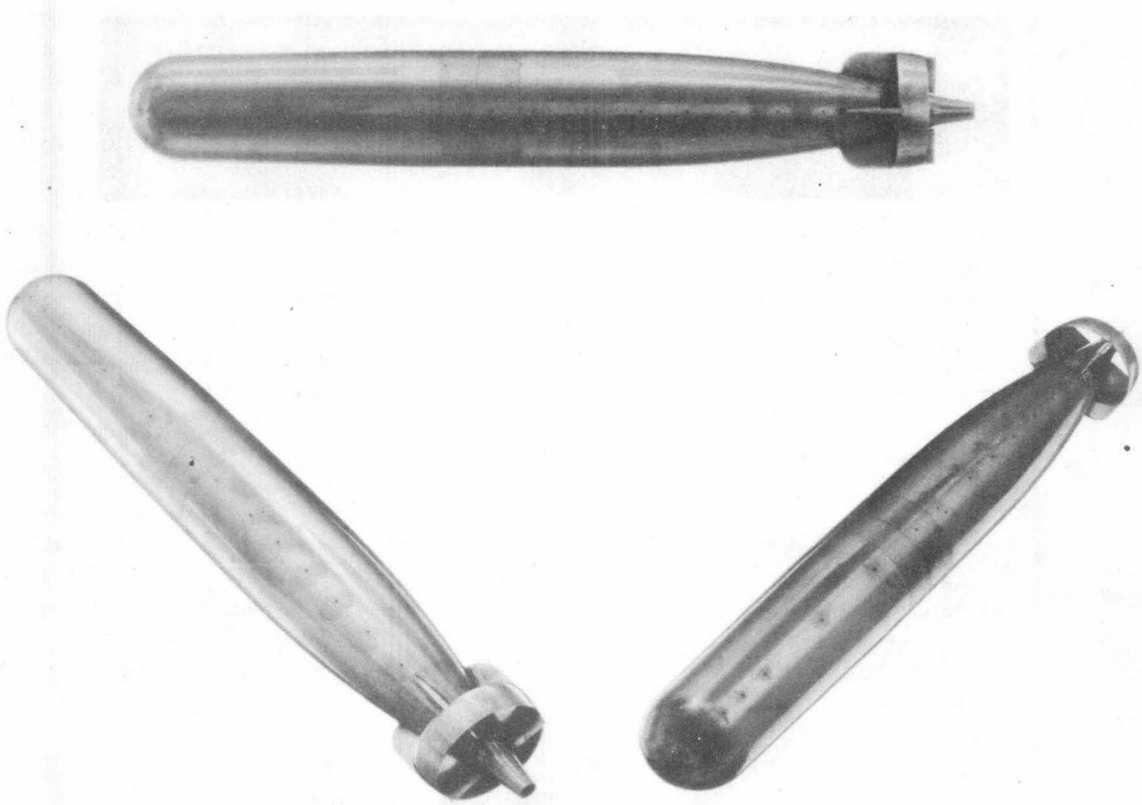


FIG. 2 - THREE VIEWS OF THE MODEL

than were possible with the MK 13-1 and is equipped with a newly designed power plant and control system. Figure 1 shows the outline and overall dimensions of this torpedo.

The exact form of the exhaust stack to be adopted on the final design was not known at the time these tests were initiated.

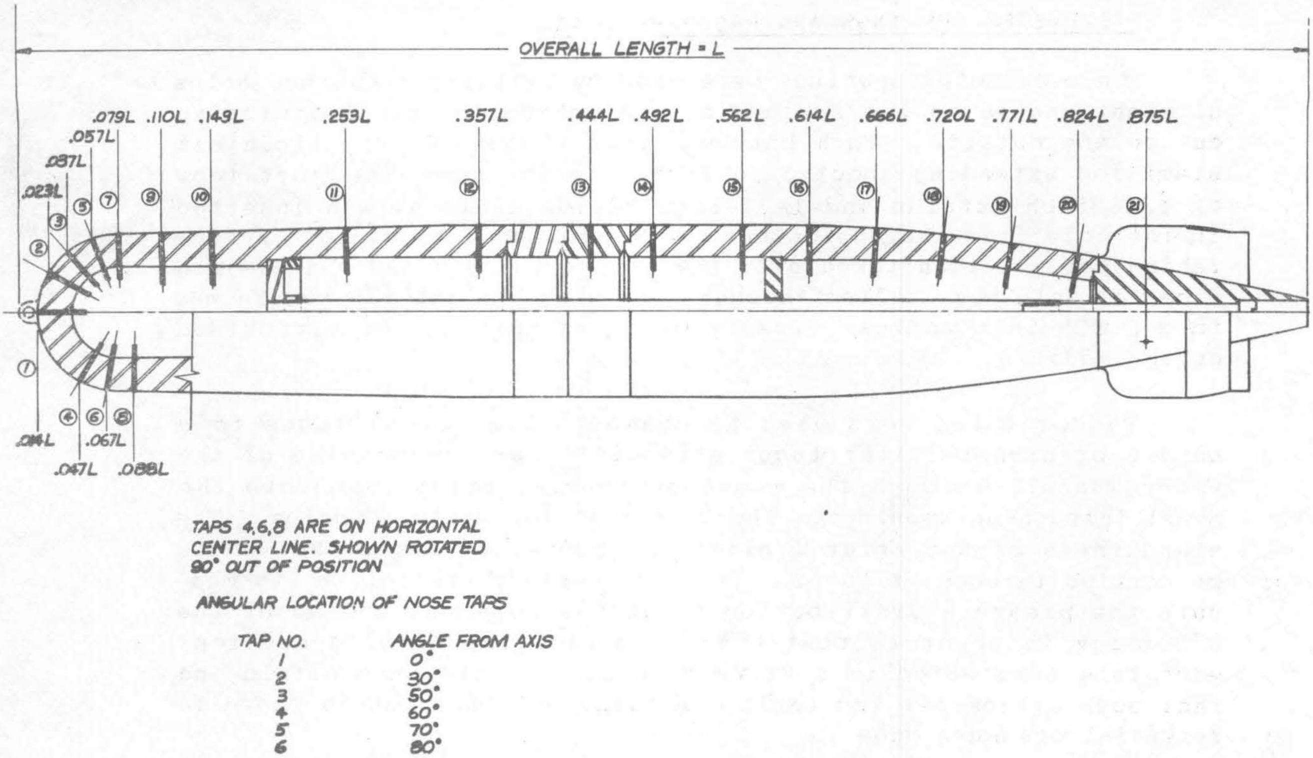


FIG. 3 – SHOWING LOCATION OF PRESSURE TAPS

It was decided, therefore, to make these tests on a model equipped with a shroud ring but without exhaust stacks. However, previous tests on the Mk 13 Torpedo showed that the pressure distribution on the body was very little affected by the presence of the entire fin and ring structure. Therefore, the absence of the exhaust stacks on the ring should make no detectable difference in the measurements.

MODEL CONSTRUCTION

The stainless steel model used in these tests is shown in Figures 2 and 3, and has a maximum diameter of 2 inches (model scale 1:11.21). The model consists of a hollow forebody, hollow afterbody, and separate tail cone, all supported by the spindle-mounted center section. The rudders on the tail cone are all fixed in neutral position. The forebody, afterbody, and tail cone were so made that each part could be rotated about the longitudinal axis independently of the other parts. With this arrangement, a single row of piezometer openings distributed along a meridian is sufficient for exploring the pressure distribution about the entire body. To avoid crowding the piezometer taps on the nose, three of them were located on a line at right angles to the main row of taps (see Figure 3). A protractor scale scribed at the joint line of each body section and graduated in 5-degree intervals, provides the means for setting the angular position of the piezometer taps.

PIEZOMETER OPENINGS AND PRESSURE LEADS

The piezometer openings were made by drilling 1/16-inch holes at right angles to the surface before making the final finishing cut on the outside. Each hole was then plugged with a stainless steel rod extending about 3/16 inch into the body. A brass tube of 1/16-inch outside and 1/32-inch inside diameter was inserted in the hole from the inside and silver soldered in place. A finishing cut was then taken over the entire surface and a 1/32-inch diameter hole was drilled through each plug and its lip was reamed to a 0.005-inch radius. Twenty-one such openings were provided on the model.

Rudder tubes were used to connect these brass tubes to a bundle of nickel-silver tubes extending from the outside of the Water Tunnel, through the model supporting strut, and into the model through an opening in the bottom of the center section. The slenderness of the strut limited the number of tubes that could be carried through it to 12. It was necessary, therefore, to measure the pressure distribution about the forebody and about the afterbody in separate test runs. Outside the working section, each tube terminated in a valve mounted on a common manifold, so that each piezometer tap could, in turn, be connected to the differential pressure gage.

DIFFERENTIAL PRESSURE GAGE

The differential pressure gage used in these tests consists of two opposed piston and cylinder units and an automatically weighing beam-type balance. The two opposing pistons are interconnected with a yoke system which also connects to the beam of the balance. Thus, the force transmitted to the balance is proportional to the difference between the pressures applied against the two pistons. The cylinders are continuously rotated by an electric motor to overcome static friction. Another motor, controlled through a photoelectric cell by the rise and fall of the balance beam, shifts a rider weight along the beam to balance the applied force. A veeder counter connected to the rider drive is geared to read the differential pressure directly in pounds per square inch to 0.001 psi.

TEST PROCEDURE

The pressure distribution around the torpedo was explored by setting the piezometer openings at a given angle and measuring the pressure at each tap for yaw angles of 0, ± 3, and ± 6 degrees. The piezometer tap settings were varied from 0 to 90 degrees in 15-degree steps. Because of the symmetry of the torpedo, these measurements give the pressure distribution about the entire body. Most of the tests were made with a constant velocity of 40 feet per second and constant static pressure in the tunnel working section of 10 psi. Several test runs were made with different velocities and static pressures to determine the effect of these variables on the pressure distribution.

The static pressure reference was taken at the tunnel wall at a point 5.25 model diameters upstream of the model nose. The differential pressure measured at each piezometer opening was corrected for tunnel pressure gradient by subtracting from it, the tunnel pressure drop, measured in the absence of the model, between the reference point and a point opposite that piezometer opening.

TEST RESULTS

PRESENTATION

The test results are shown in Figures 4 to 12, inclusive, and are presented in terms of p/q, where

$p = P - P_o$

P = pressure on the surface of the torpedo, pounds per square foot

P_o = static pressure in undisturbed water at same level as torpedo center line, pounds per square foot

$q = 1/2 \rho V^2$ = dynamic pressure of water, pounds per square foot

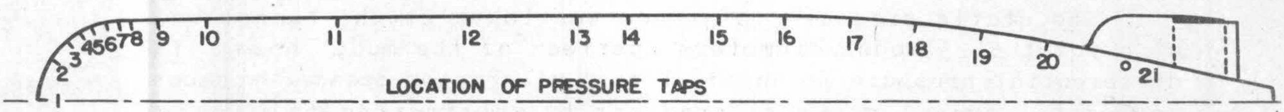
ρ = mass density of water, slugs per cubic foot

V = mean water velocity, feet per second

LONGITUDINAL PRESSURE DISTRIBUTION - ZERO YAW

In Figure 4 is shown the longitudinal pressure distribution around the torpedo at zero yaw, plotted against distance from the tip of the towing ring divided by overall length. It is evident that for a symmetrical body oriented with its axis parallel to the direction of motion, the pressure around any section normal to the axis should be constant. It is seen that the seven points plotted for each pressure tap show very little scatter except for Tap No. 20. This tap is a short distance ahead of the leading edges of the fins and the pressure there is affected by the proximity of the fins, being higher when the tap is immediately in front of a fin; that is, when the tap is either on the horizontal or on the vertical center line.

From full stagnation pressure at the tip of the nose, the pressure drops rapidly to about 0.72 q below static and then rises again, but remains below static pressure over almost the entire length of the torpedo. Where the afterbody begins to taper down, there is a further decrease in pressure followed by a rise to approximately static pressure slightly ahead of the leading edges of the fins. The pressure on the body equals the static pressure (p/q = 0) at two stations, one on the nose and one on the afterbody.



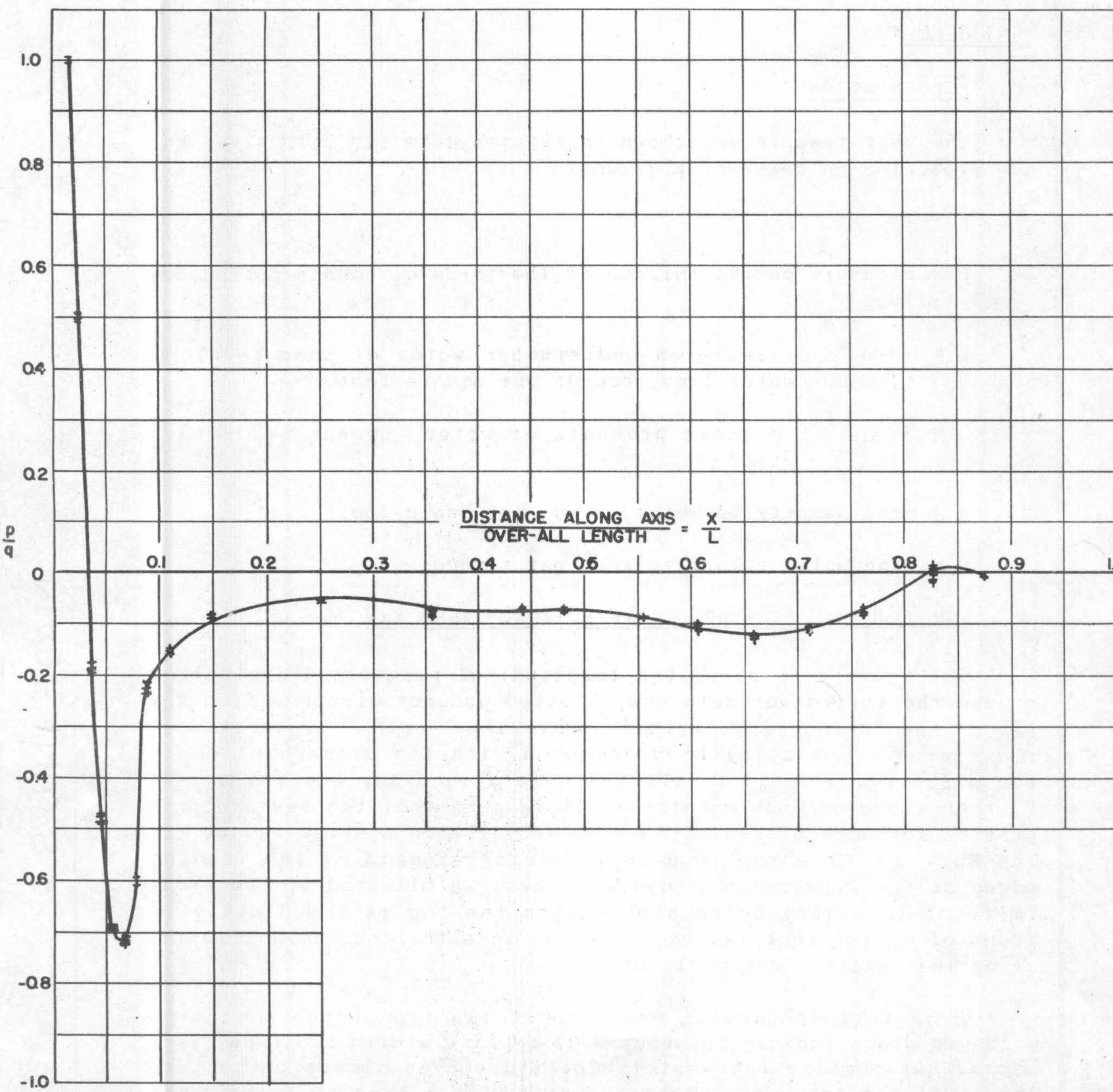


FIG. 4 — PRESSURE DISTRIBUTION ALONG LONGITUDINAL SECTION

(Yaw Angle = 0°)

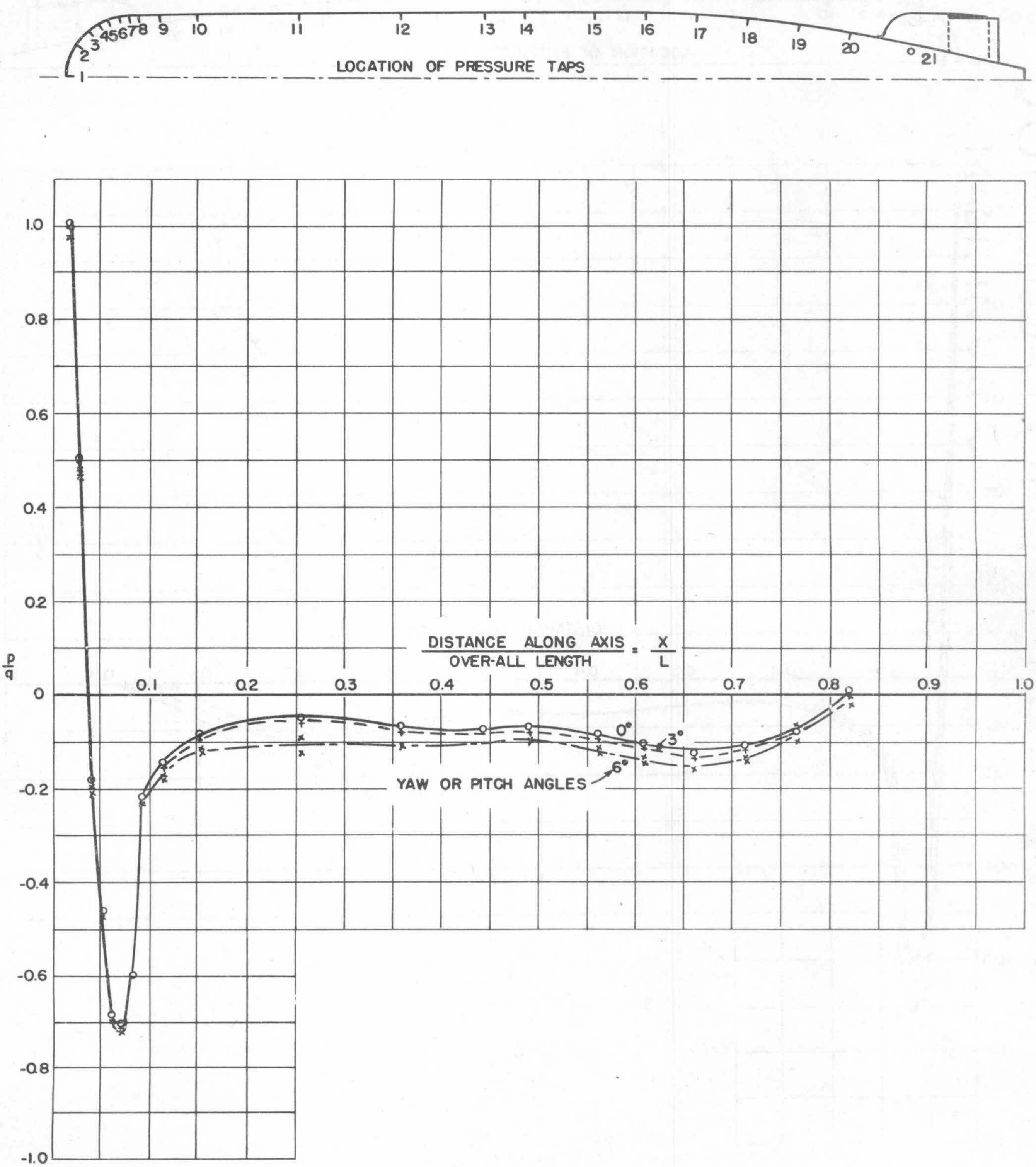
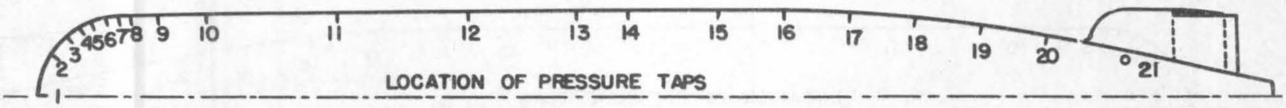


FIG. 5 – PRESSURE DISTRIBUTION ALONG LONGITUDINAL SECTION AT RIGHT ANGLES TO PLANE OF YAW OR PITCH



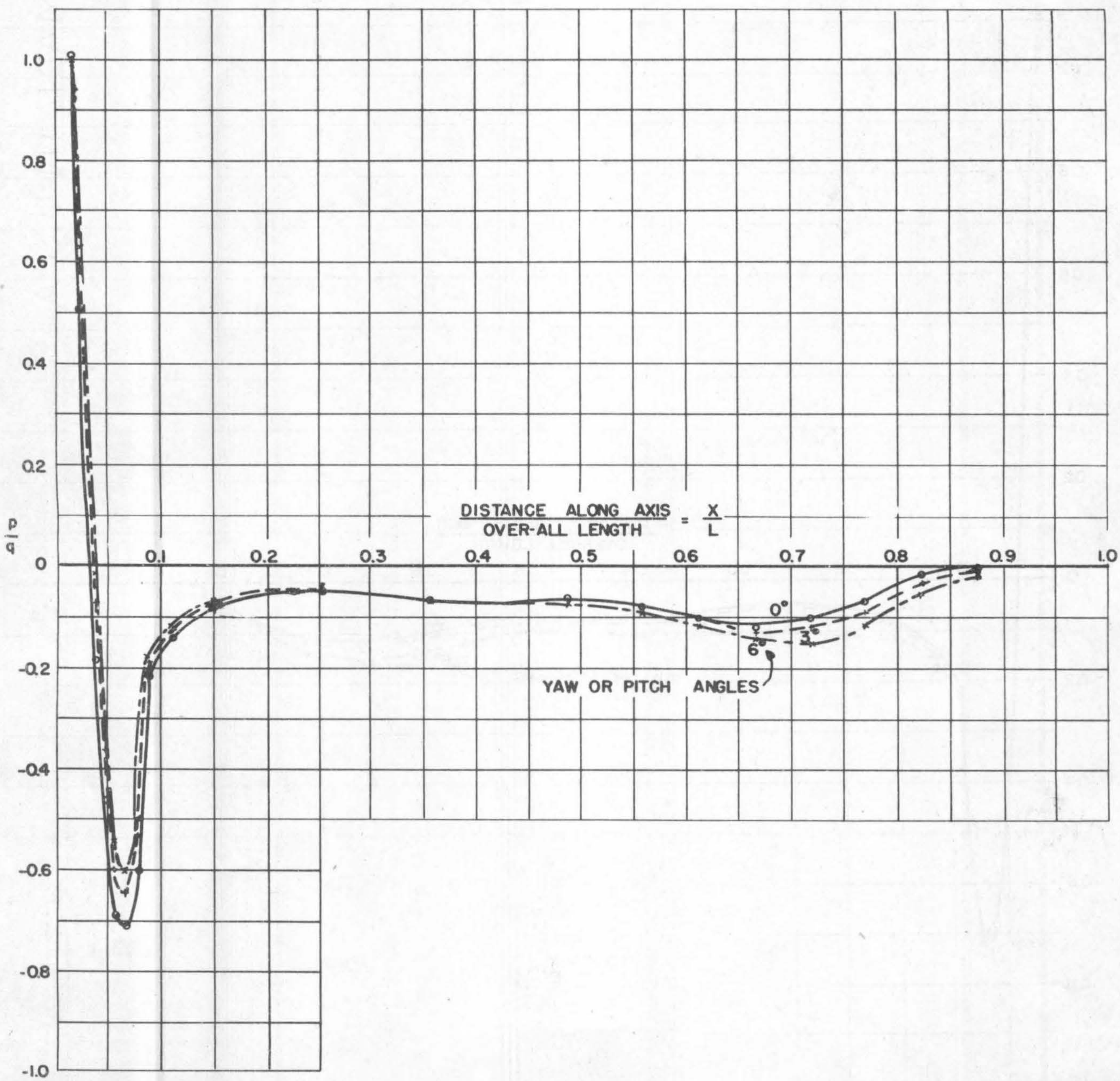


FIG. 6 — PRESSURE DISTRIBUTION ALONG LONGITUDINAL SECTION

AT 45^{0} TO PLANE OF YAW OR PITCH

Windward Side of Body

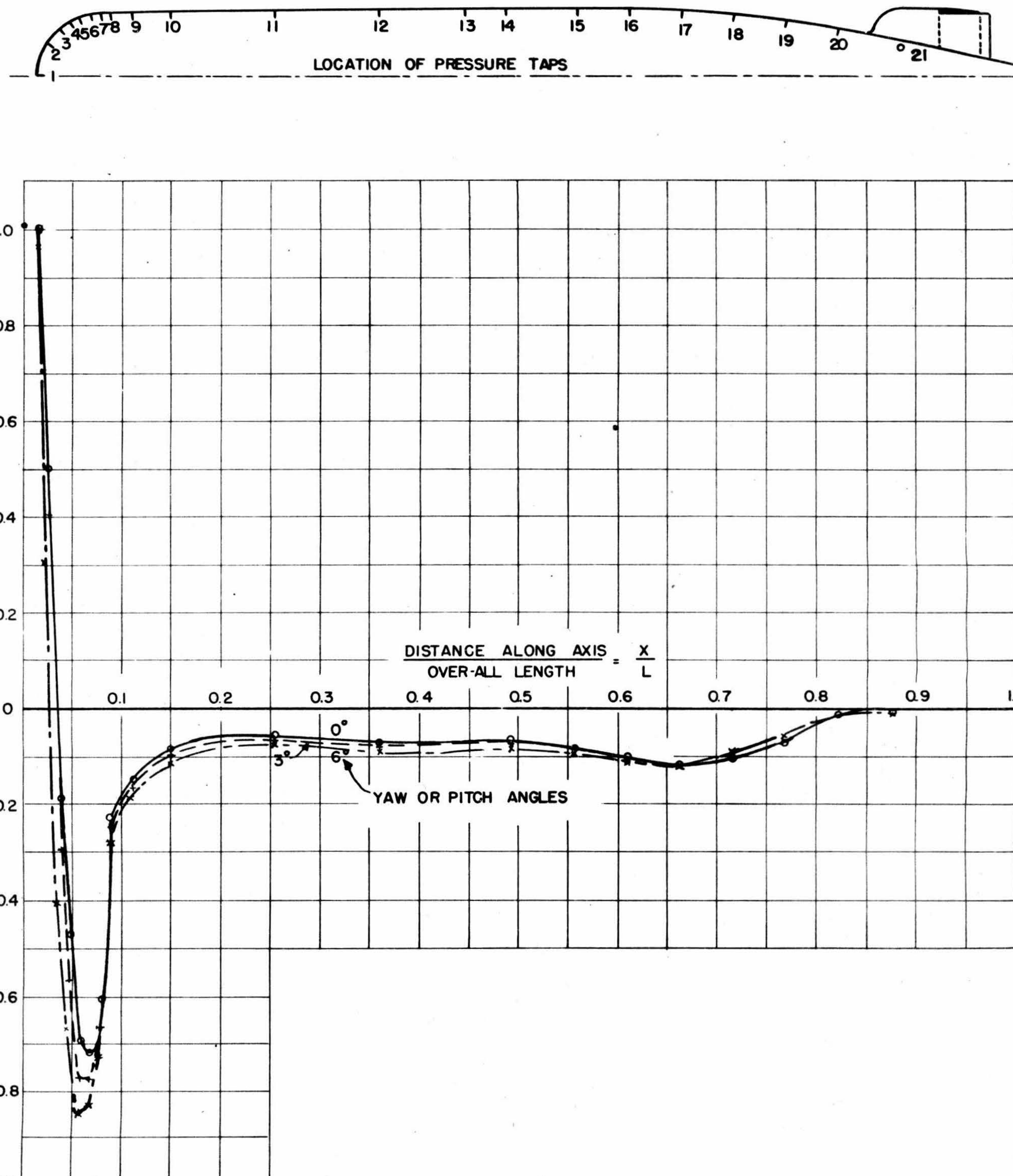


FIG. 7 — PRESSURE DISTRIBUTION ALONG LONGITUDINAL SECTION

AT 45° TO PLANE OF YAW OR PITCH

Lee Side of Body

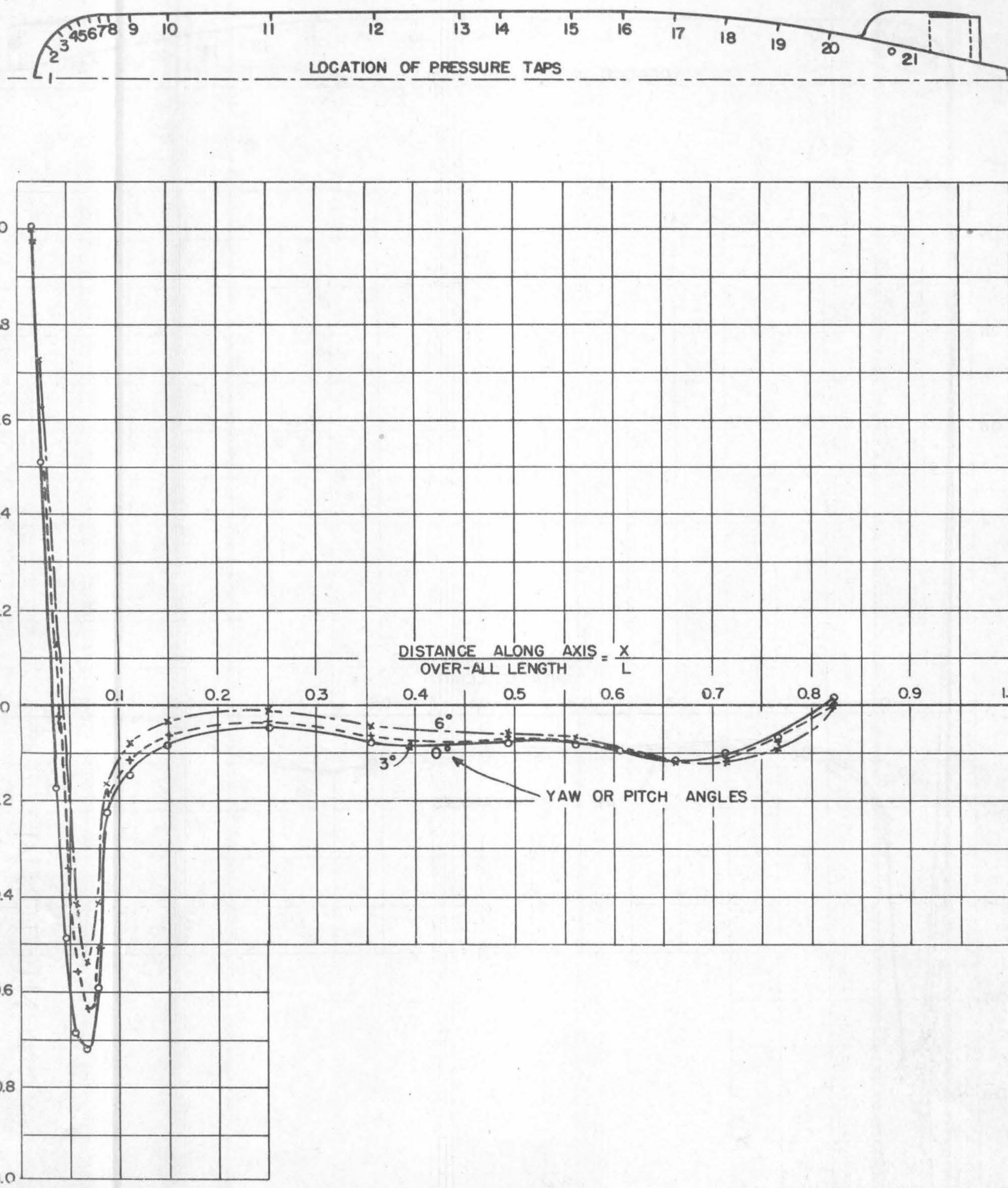
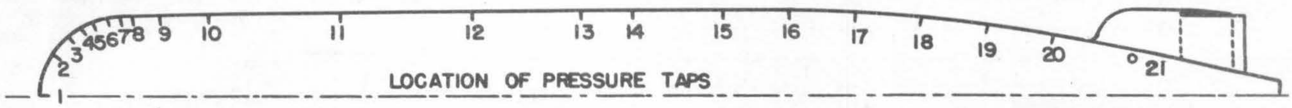


FIG. 8 – PRESSURE DISTRIBUTION ALONG LONGITUDINAL SECTION

IN PLANE OF YAW OR PITCH

Windward Side of Body



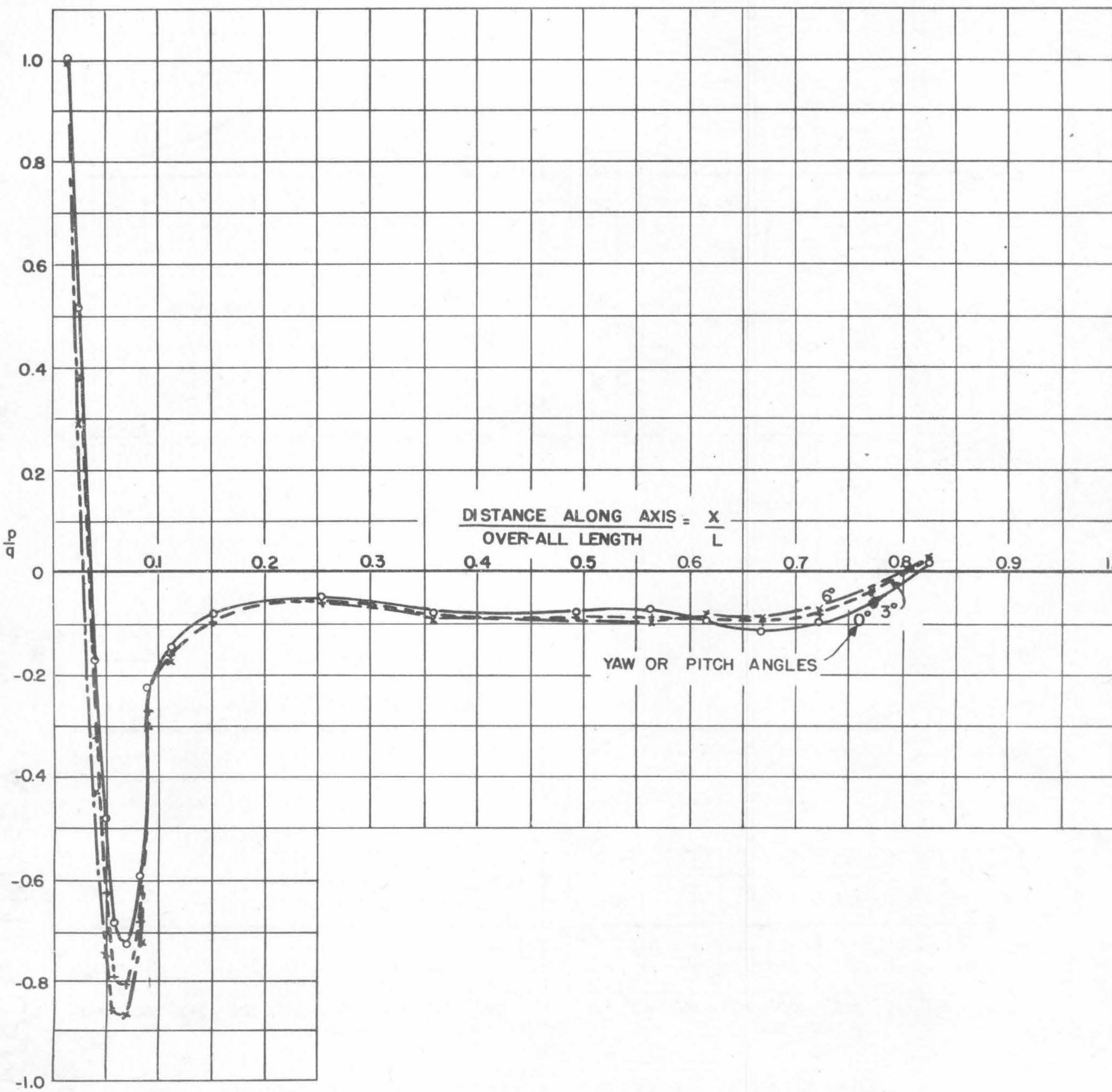


FIG. 9 — PRESSURE DISTRIBUTION ALONG LONGITUDINAL SECTION

IN PLANE OF YAW OR PITCH

Lee Side of Body

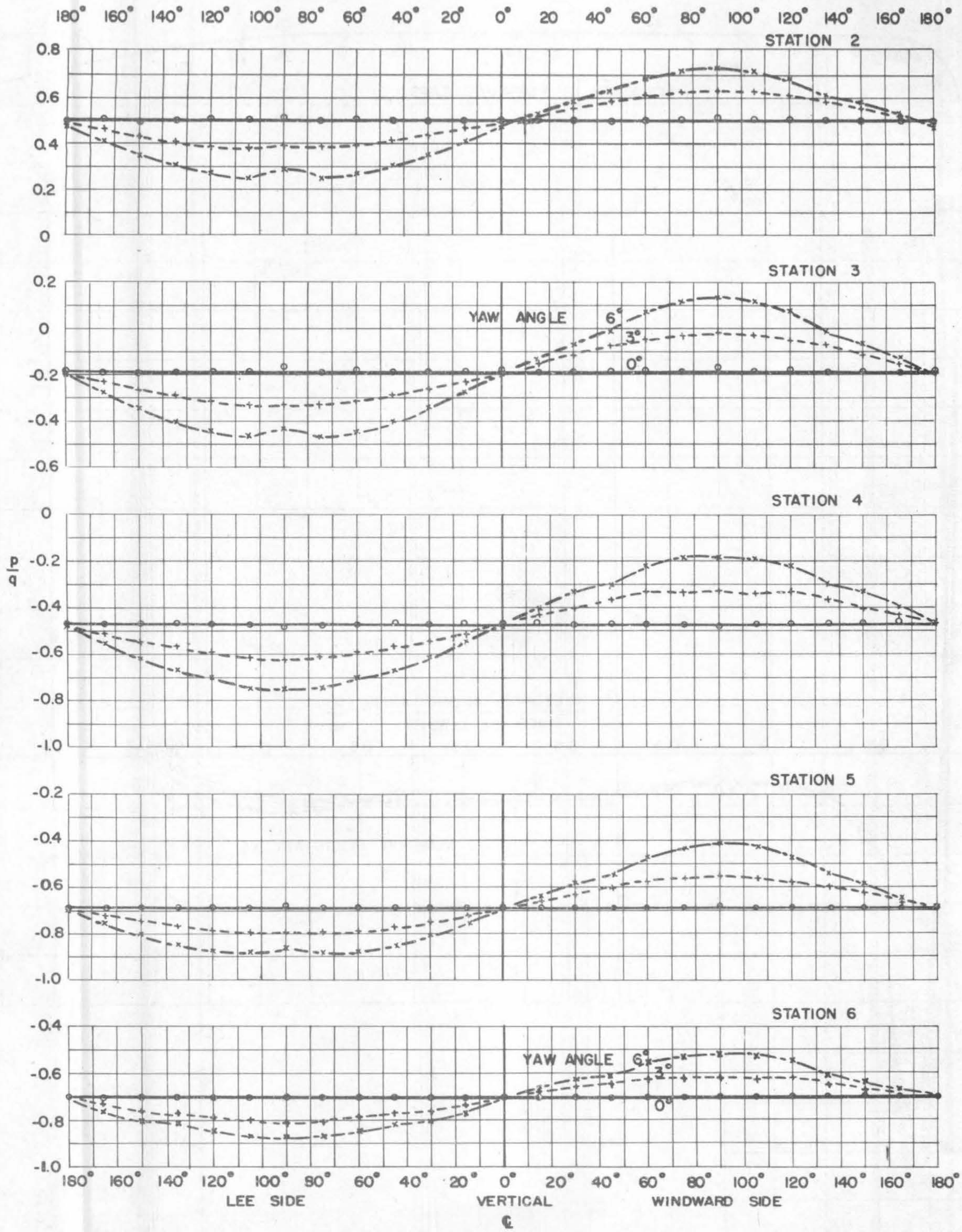


FIG. 10 — PRESSURE DISTRIBUTION ABOUT NORMAL CROSS SECTIONS AT STATIONS ON FOREBODY

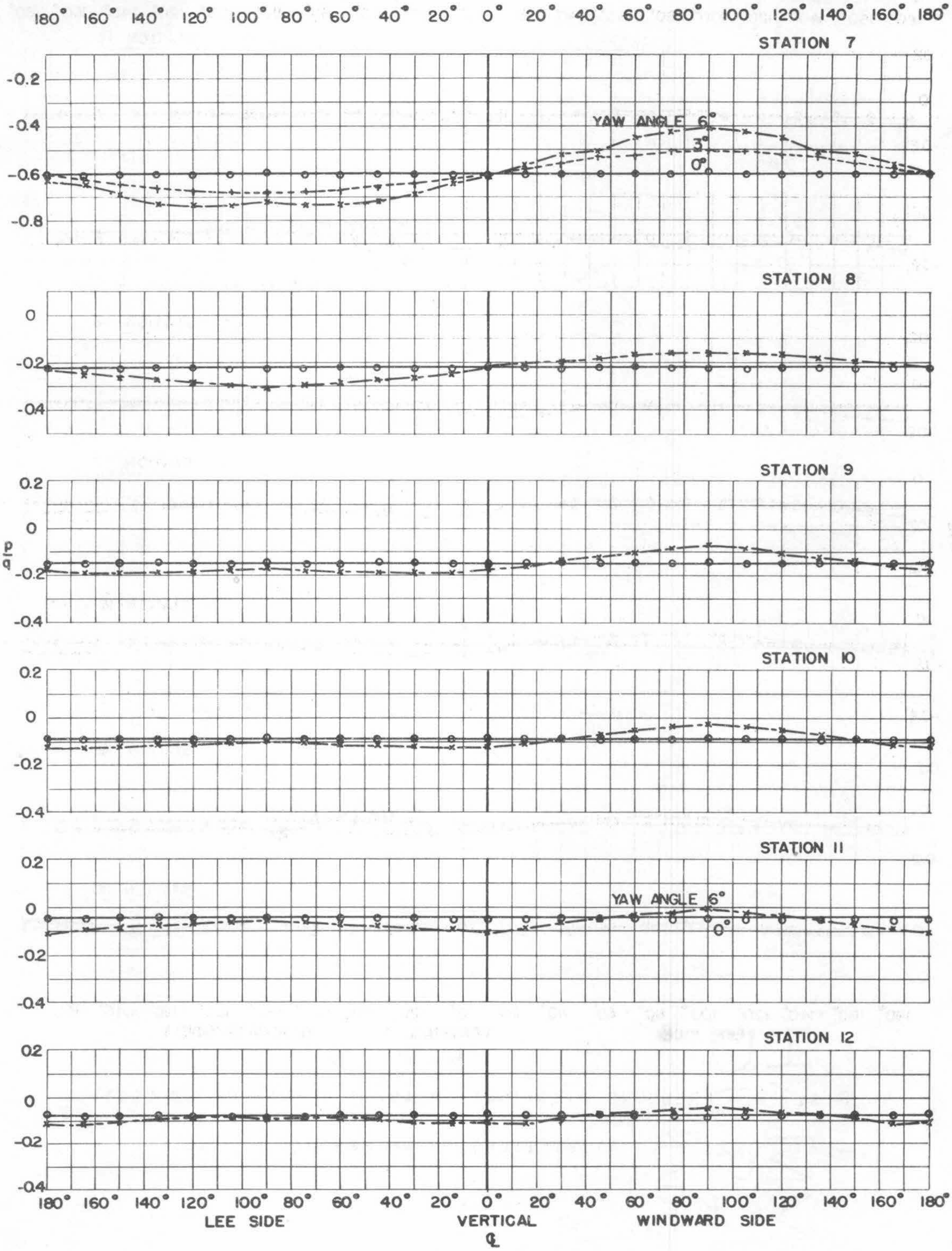


FIG. 11 - PRESSURE DISTRIBUTION ABOUT NORMAL CROSS SECTIONS

AT STATIONS ON FOREBODY

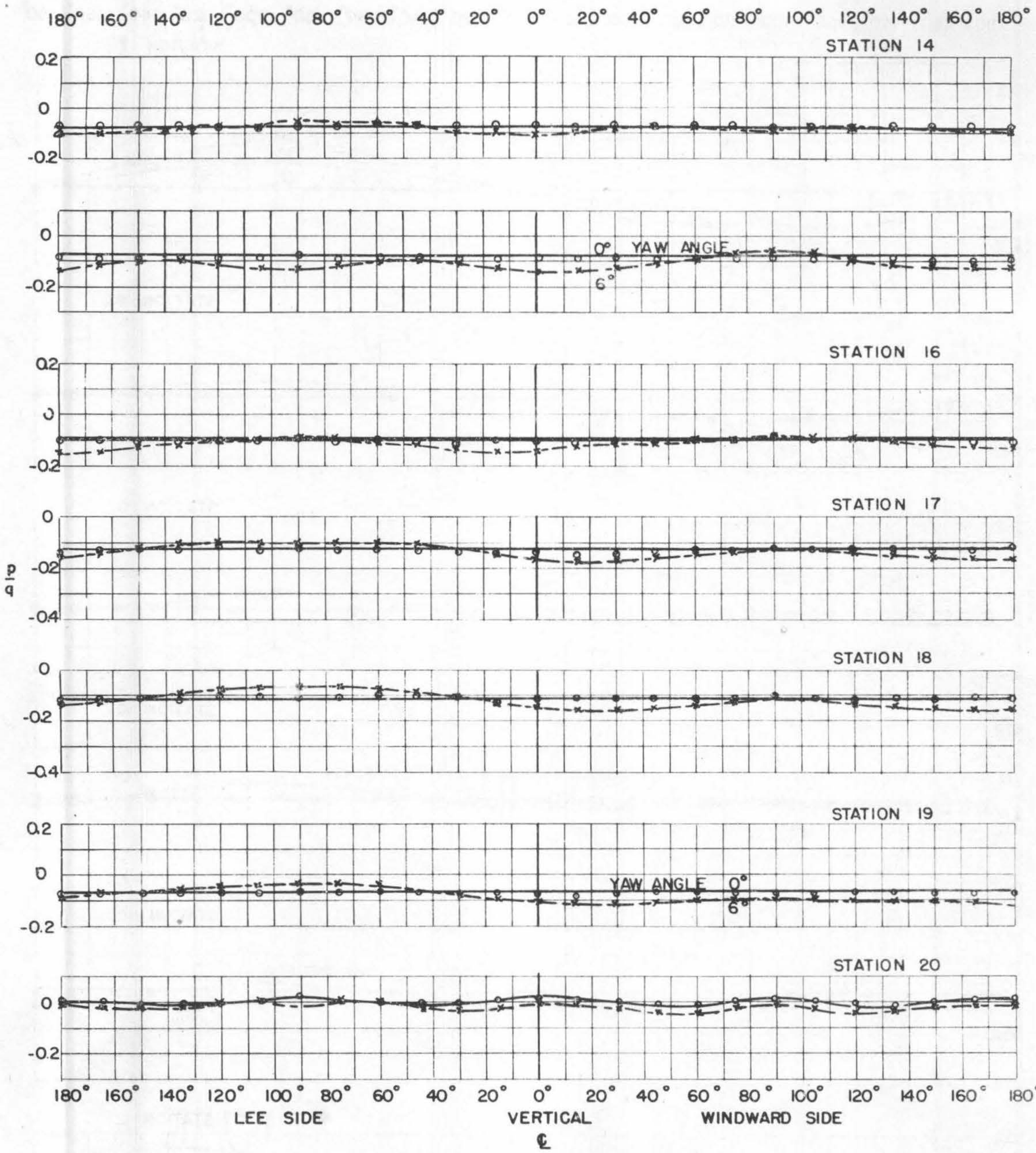


FIG. 12 — PRESSURE DISTRIBUTION ABOUT NORMAL CROSS SECTIONS AT STATIONS ON AFTERBODY

YAW EFFECTS ON LONGITUDINAL PRESSURE DISTRIBUTION

Figure 5 shows the longitudinal pressure distribution on the body as it is affected by yaw or pitch. These curves show the pressure along a longitudinal section at right angles to the plane of yaw or pitch. From a consideration of the symmetry of the body, it is evident that the pressure distribution along the top and bottom meridians when the torpedo yaws to either starboard or port, is exactly the same as the pressure distribution along the sides (on the horizontal meridians) of the torpedo as it pitches up or down. It is seen that the effect of yaw or pitch is to lower the pressure over the entire length, only slightly for angles below 3 degrees, and more noticeably for larger angles.

In Figures 6 and 7 is shown the longitudinal pressure distribution on the windward and lee sides of the body, respectively, along meridians at 45 degrees with the planes of yaw or pitch. It is seen that yaw causes the pressure on the nose to increase on the windward side and to decrease on the lee side. Along the mid-portion of the hull, the pressure on the windward side is practically independent of yaw or pitch, and on the lee side it decreases slightly with yaw. On the afterbody taper the pressure decreases with yaw or pitch on the windward side and increases slightly on the lee side. In the vicinity of the tail fins (at Tap 21) the pressures are affected by the fins, and on the lee side the direction of change in pressure due to yaw is again reversed.

Figures 8 and 9 show the longitudinal pressure distribution along the windward and lee sides of the body, respectively, along a section in the plane of yaw or pitch, i.e., along the top and bottom if pitching, and along the sides when yawing. It is seen that on the nose and midsection, the pressure rises on the windward side and drops on the lee side when the torpedo is yawed, whereas on the afterbody this relationship is reversed.

PRESSURES AROUND CROSS SECTIONS NORMAL TO TORPEDO AXIS

In Figures 10 to 12, inclusive, are presented the transverse pressure distributions around cross sections taken normal to the axis of the torpedo at each piezometer opening or station. The curves show the pressures for yaw angles of 0, 3, and 6 degrees, plotted against body angles measured to either side from the vertical center line. Again, from symmetry considerations, it is evident that these curves give also the pressure distribution when the torpedo is pitching, if we measure the angles from the horizontal center line instead of the vertical. Also, the angles may be reckoned from either end of the center line (i.e., either from top or bottom, or from port side or starboard side) since the pressure distribution is symmetrical about the 90-degree points on windward and lee sides. Figures 10 and 11 cover the stations on the forebody, and Figure 12 gives the pressure distribution on the afterbody.

It will be noted that Stations 1, 13, and 21 are not shown on these curves. Station 1 is at the tip of the nose, Station 13 is on the fixed center section which could not be rotated, and Station 21 is on the tail cone which was also held stationary.

EFFECT OF VELOCITY AND STATIC PRESSURE

The tests presented thus far were all made with a water velocity of 40 feet per second and a static pressure in the working section of the tunnel of 10 pounds per square inch. Another series of tests were made with velocities of 32, 40, and 50 feet per second and static pressures of 5, 15, and 25 pounds per square inch. These tests showed that, within the range investigated, the velocity and static pressure have no measurable effect on the pressure distribution.

CALCULATION OF FORCES FROM PRESSURE DISTRIBUTION

With the pressure distribution about a projectile completely known, it is possible to calculate from the pressure distribution data the form drag (but not skin friction drag), the cross force and the moment acting at any yaw angle by proper integration of the distributed pressure forces. These tests, however, were all made o. a body with tail surfaces, and the pressures on these surfaces themselves were not measured because of the thinness of the sections. Therefore, the forces acting on the torpedoes cannot be calculated from the data presented herein.

CAVITATION AND PRESSURE DISTRIBUTION

Cavitation, or the formation of vapor-filled cavities, occurs in hydraulic machinery or on underwater projectiles when the pressure at any point on the body becomes equal to the vapor pressure of the water. A knowledge of the pressure distribution around a projectile should, therefore, give an indication of the susceptibility of the projectile to cavitate. As defined in the preceding section, the data presented herein are given in terms of

$$\frac{p}{q} = \frac{P - P_o}{1/2\rho V^2}$$

In order to have cavitation, the pressure on the body, P, must equal the vapor pressure, P_v, or

$$P_v = P = \frac{p}{q}\, 1/2\rho V^2 + P_o$$

From the above equation it is evident that cavitation cannot occur on the body at a point having a positive value of (p/q), for then the static pressure P_o must be lower than P_v, and the entire volume of the liquid would boil. With a negative (p/q), it is seen that, for a given water temperature (i.e., given P_v), cavitation conditions are approached as P_o is lowered or as V is increased. As cavitation is brought about, it will begin at that point on the body having the lowest value of (p/q). Thus, the lowest value of (p/q) measured on the body is an index of its susceptibility to cavitation, and is normally given as the cavitation parameter, K, which is defined by

$$K = \frac{P_o - P_v}{1/2\ \rho V^2}$$

Comparing this equation with the expression for (p/q), it is seen that $K = -(p/q)_{mim}$, i.e., the cavitation parameter for the inception of cavitation on any shape is equal, but of opposite sign, to the lowest value of (p/q) measured on that body.

The curve of Figure 4 indicates, therefore, that the inception of cavitation on this torpedo should occur at a K value of about 0.72. This differs slightly from the value 0.67 determined from direct observation of the inception of cavitation. The reason for this deviation is not clearly known at present.

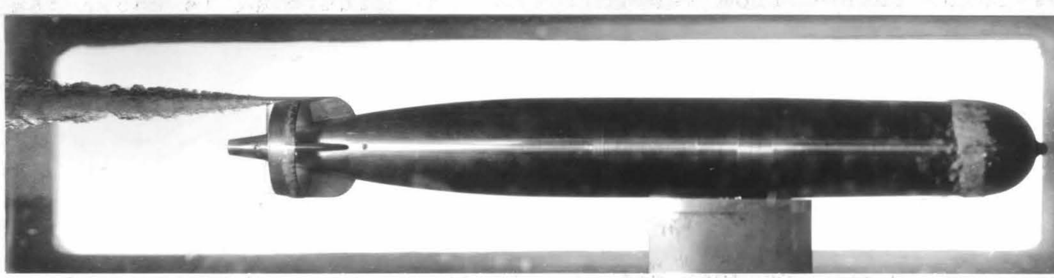


FIG. 13 - SHOWING CAVITATION ON THE NOSE AT K = 0.53

Figure 13 shows cavitation on the nose of a model of the Mark 25 torpedo installed in the working section of the Water Tunnel and operating under velocity and pressure conditions giving a value of K of 0.53, which is lower than that required for inception of cavitation, and corresponds to a speed of 45 knots and a submergence of 5 feet. Referring to Figure 4 again, it is seen that cavitation should occur in the zone having (p/q) values below 0.53, and that zone is just ahead of the junction of the hemispherical nose tip and the forebody taper. Figure 13 shows that the cavitation actually occurs at the zone just aft of this junction. It appears, therefore, that a definite time interval is required for a bubble to grow to visible size, and during that interval the bubble is swept downstream. As the bubbles are carried further downstream into a zone of higher pressure, they collapse and disappear. This photograph was taken with another model of the Mk 25 having a short exhaust stack and is shown discharging air through the stack.

PRESSURE INTAKES FOR DEPTH CONTROL AND DEPTH AND ROLL RECORDER

DEPTH CONTROL

To enable a torpedo to travel at set depth under all conditions of speed and orientation with the direction of travel, it is necessary that the pressure impressed upon the hydrostatic diaphragm of the depth-control mechanism be at all times equal to the static pressure of the water at the actual running depth of the torpedo. This is best accomplished by locating the pressure intake to the hydrostat at a point on the body where the pressure at the surface, under all conditions of speed, yaw, and pitch, is equal to the static pressure in undisturbed water, that is, at a point where (p/q) is equal to zero at all yaw or pitch angles. Also, the intake opening should be flush with the surface, at right angles to it, and with smooth edges. The experience of this Laboratory indicates that piezometer openings with slightly rounded edges (to a radius of about 1/6 the bore diameter) are more accurate and reliable than sharp-edged openings.

Figure 4 shows that on the Mark 25 afterbody, (p/q) = 0 approximately at Pressure Tap 20 where X/L = 0.824, or a distance of 28.35 inches from the tail end. In Figure 12 is shown the pressure distribution around this station for zero yaw and for 6 degrees yaw. It is seen that the pressure rises at the quadrant points (0, 90, and 180 degrees) because of the effect of the fins whose leading edges are just downstream from this station. Between the fins, at the 45-degree points, the pressure drops to slightly below static. It appears, therefore, that the best arrangement for an intake to the hydrostat would be through a piezometer ring connecting to four small openings on the 45-degree planes at a section just aft of Station 20, or a distance of about 28 inches from the end of the tail.

With the pressure intake at any other location on the afterbody, it is evident from the pressure distribution curves that the pressure at the surface would, for a given yaw angle, differ from true static pressure by a fixed fraction of the velocity head. For a single-speed torpedo, the pressure impressed on the diaphragm would differ from static pressure by a constant number of feet, and this can be taken into account in the calibration of the depth setting mechanism. However, such an arrangement would still be subject to pressure variations due to yaw.

INFLUENCE OF PROPELLERS

It should be noted that the tests reported herein were made on a model without propellers. The operation of the propellers on the prototype torpedoes may modify the pressure distribution on the afterbody, so that the best location for the pressure intake may be slightly ahead or aft of the position indicated above.

DEPTH AND ROLL RECORDER

The requirements discussed in the preceding paragraphs in connection with the location and design of the pressure intake for the depth control mechanism apply also to the pressure intake for the hydrostatic diaphragm of the depth and roll recorder, if the instrument is to record true running depth. Since this instrument is installed in the head, it would not be practicable to connect it to the point on the afterbody where $p/q = 0$. Connection to the point on the nose where $p/q = 0$ is not recommended because at this point the pressure varies greatly with yaw or pitch. If the depth and roll recorder does not record true depth, it would probably be best to determine the magnitude of the error and apply a correction.

It should be borne in mind that the depth control mechanism and the depth and roll recorder should not be used as primary instruments to check each other, because it is possible to have the torpedo run above or below set depth and, at the same time, to get a depth record which indicates a run at set depth. The pressure distribution curves show that the pressure over most of the surface of the torpedo is lower than static pressure. It is possible, therefore, that the pressures impressed on both depth control and depth and roll recorder diaphragms are lower than static pressure. In this case, the torpedo would run below set depth but the depth and roll recorder would indicate a depth shallower than the actual running depth, and thus the error may not be detected.

REFERENCES

(1) "Water Tunnel Tests of the Mk 25 Torpedo with Gas Exhaust Through a Vertical Fin," Section No. 6.1-sr207-1275, H. L. Doolittle, CIT, May 8, 1944.

(2) "Water Tunnel Tests of the Mk 25 Torpedo with Gas Exhaust through a Horizontal Pipe," Section No. 6.1-sr207-1640, H. L. Doolittle, CIT, June 5, 1944.

(3) "Water Tunnel Tests of the Mk 25 Torpedo with Expanding Exhaust Pipe," Section No. 6.1-sr207-1642, H. L. Doolittle, CIT, June 20, 1944.

(4) "Mk 25 Torpedo Exhaust Gas Investigation," Section No. 6.1-sr207-1916, H. L. Doolittle, CIT, April 12, 1945.

(5) "Mk 25 Torpedo with Various Exhaust Pipes," Section 6.1-sr 207-2236, H. L. Doolittle, CIT, July 14, 1945.